5-25-1969

Pattern recognition by means of electric stimuli

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A THESIS PRESENTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE MASTER OF SCIENCE DEGREE IN PHOTOGRAPHIC SCIENCE AND INSTRUMENTATION AT THE ROCHESTER INSTITUTE OF TECHNOLOGY, ROCHESTER, N.Y.

PATTERN RECOGNITION BY MEANS OF ELECTRIC STIMULI

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DATE: MAY 16th, 1969.

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Accepted May 25, 1969
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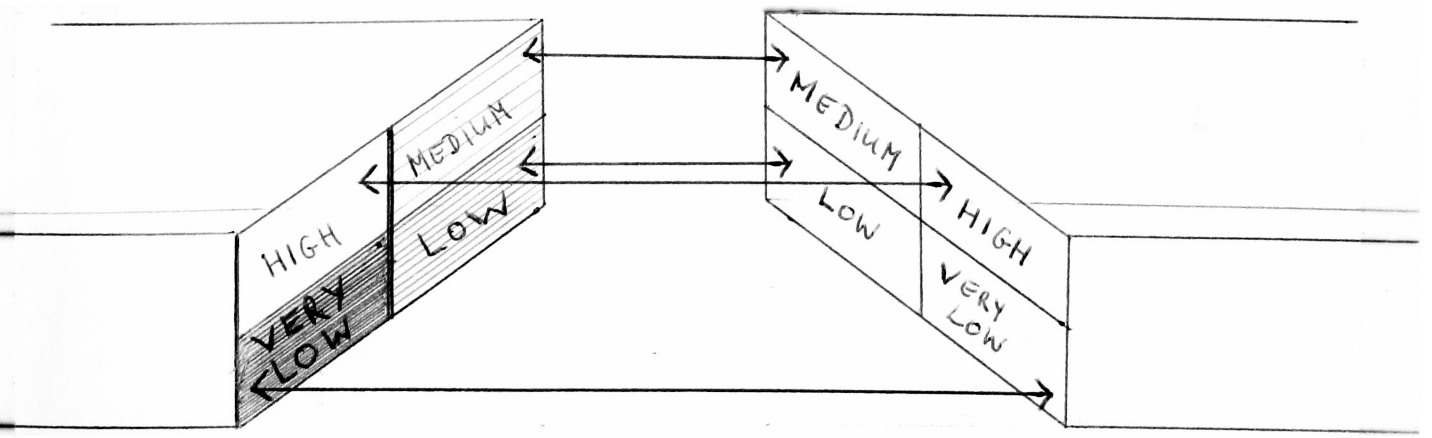
INTRODUCTION

At present, the only method whereby the blind are able to read is Braille. The chief limitations of Braille are as follows:

1. The conversion from ordinary printed material to Braille cannot be undertaken by the blind person alone. It involves a process, the duration of which may prove inconveniently long for the blind person.
2. Braille has no third or "intensity" dimension , as would be needed, e.g., to see a photograph. It is simply a black-white, on-off type system.
3. A Braille book is often inconveniently bulky and the whole process of printing such a book is expensive.

This paper will attempt to suggest a device that may overcome all of the three factors listed above.

Consider the following simple schematic diagram.



LUMINANCE--VOLTAGE

FIGURE I

The left hand diagram represents a simple "scene" consisting of four squares with luminances (i.e., amount of reflected light energy per unit area) ranging from low to very high.

The right hand diagram is a "reading board" on which voltages are produced in proportion to the luminances from the "scene". Areas on the "scene" correspond spatially to areas on the board: e.g., the top right-hand corner of the board has a medium voltage corresponding to the medium luminance from the top right-hand corner of the "scene".

Now, if a blind person examines the board with his fingertip, the base of which is grounded electrically, and provided that the voltages are of suitable form and strength, he will then feel an electric current passing through his fingertip. The current strength, and hence the intensity of sensation, will be related to the luminance from the "scene". He is thus able to trace out patterns according to the existence or non-existence of sensation, and also to appreciate "brightness" according to the degree of sensation felt.

It should be pointed out now that there are two distinct parts to this device.

The first part involves the relationship between the luminance of the "scene" and the voltage on the board. The success of this part depends on the degree of sophistication of electronics, etc., and will be better examined by those expertly qualified to do so.

The second part involves the human factor, i.e., the ability of the blind person to interpret the resulting sensations. It is clear that if, for one reason or another, this part is unsuccessful, then no amount of electronic sophistication in the first part can help.

Accordingly, this paper discusses various experiments involving electrical stimuli performed on blind subjects.

OBJECTIVES:

1. What minimum "threshold" voltage is needed at the point where the subject touches the board in order for him to detect a sensation there?
2. What is the Just Noticeable Difference (JND) in voltage required between two points in order for the subject to say which is higher on the basis of subjective sensation?
3. Can simple spatial patterns of electrical stimuli be identified?
4. If more than two points are presented, each with differing voltages, can the subject successfully rank them in terms of subjective sensation?
5. What effect does the narrowing of the spacing between two points have on the subjects' evaluation of the sensation at each point?

EXPERIMENTAL PROCEDURE

I. Apparatus

Broadly speaking, the apparatus consists of two main parts. The first consists of the electronics that supplies the voltage to the reading board. The second is the board itself.

A. ELECTRONICS: A simple schematic of the first part is shown below.

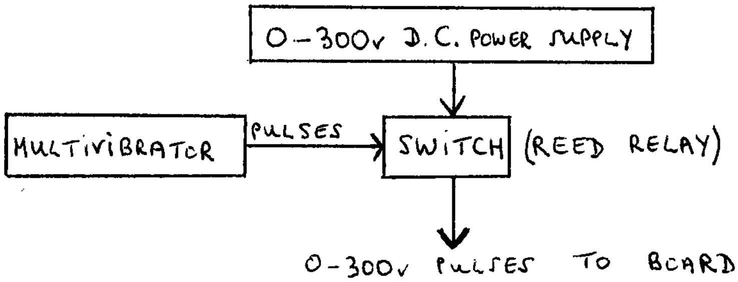


FIGURE II

The multivibrator circuit can be found in Appendix I.

The multivibrator was designed to produce six volt pulses of approximately one millisecond width and a frequency of 30 pulses per second. The six volts are needed to operate the switch (see figure above). The width and frequency were decided upon as a result of some preliminary experiments by the author with himself as subject. All that was required of the voltage level was that it would produce a comfortable "buzzing" sensation at the fingertip when the level was sufficiently high. The author found that a width of

1 millisecond and a frequency of 30 pulses per second were satisfactory for this purpose. Additional experiments (again with the author as a subject) indicated that changing the pulse width and frequency made very little difference to the resulting subjective sensation, provided that the voltage level was kept constant.

The switch was of such design as to close when approximately 6 volts or more were passed through the coil around it. Less than six volts left it open. Thus the 6-volt input pulses made the switch open and close 30 times per second, staying closed each time for approximately one millisecond.

Now 0-300 volts D.C. were passed through the switch, the opening and closing of which were determined by the multivibrator, as explained above. Accordingly, the output was 0-300v pulses, with a frequency of 30 pulses per second, and a pulse width of about one millisecond.

B. THE READING BOARD: A photograph of the reading board may be seen in Figure II.

The board consists of a masonite base on which 100 1"x#12 brass escutcheon pins are mounted. They are mounted so that the heads are flush with the masonite

FIGURE III

THE READING BOARD

and are in a 10 x 10 array with a 13mm. spacing (center to center) between pins. The pin heads are circular, about 5 1/2 mm. in diameter. 100 toggle switches are mounted on another piece of masonite, attached at 90 degrees to the first piece. Thus it is possible to produce the voltage pulses at any required number or configuration of pins.

The procedure shown in Appendix II was used to obtain a simple practical set-up of the device schematically illustrated on page 1.

However, for the specific experiments that I wanted to perform, all that was necessary was to have voltages at the pins----it was not important how they got there. So the photocells were not used, voltage levels were controlled by the power supply only, and distributions of on-off pins were arranged by the corresponding switches. As shall be seen later, 0-100 KΩ variable resistance potentiometers inserted in series into a pin circuit, provided a simple method of raising or lowering the voltage at any one pin without affecting the voltage at any other pins.

As shall be noted throughout this report, voltages at the pins, and not current passing through the finger, was the physical variable that was monitored. Because the amount of current passing through the finger depends a great deal on the electrical resistance of the finger, and because this resistance can fluctuate greatly (as will be seen) and must be reported upon as a separate variable, it was not possible, or in fact desirable, to monitor current. Voltage was monitored throughout the experiments on a Tektronix Oscilloscope.

The Subjects

Subject A was a blind professor in the General Studies Department at R.I.T. He is about 35 years old and has been blind since the age of 8. His intelligence and cooperation made him an ideal first subject, because, if results were unsatisfactory with him, then they would probably have been even worse for the majority of other blind subjects.

Subject B was a blind middle-aged lady employed as a secretary at the Institute For the Blind, Rochester, N.Y.

Experimental Results

PART A — PROCEDURAL PROBLEMS

The first problem faced here was which finger the blind person was to use with which to feel the pins, and where the ground wire was to be attached.

It was decided to use the finger that seemed, on the basis of preliminary tests, to be the most sensitive to the stimulus. This would guard against possible discomfort arising out of a more sensitive finger's accidentally touching a pin. Subject A's forefinger was quite callused and therefore less sensitive than his other fingers. The calluses also led to widely differing regions of sensation across the forefinger alone. His little finger appeared most sensitive and callus-free and was used for all the tests.

The ground wire was attached as shown in the sketch below.

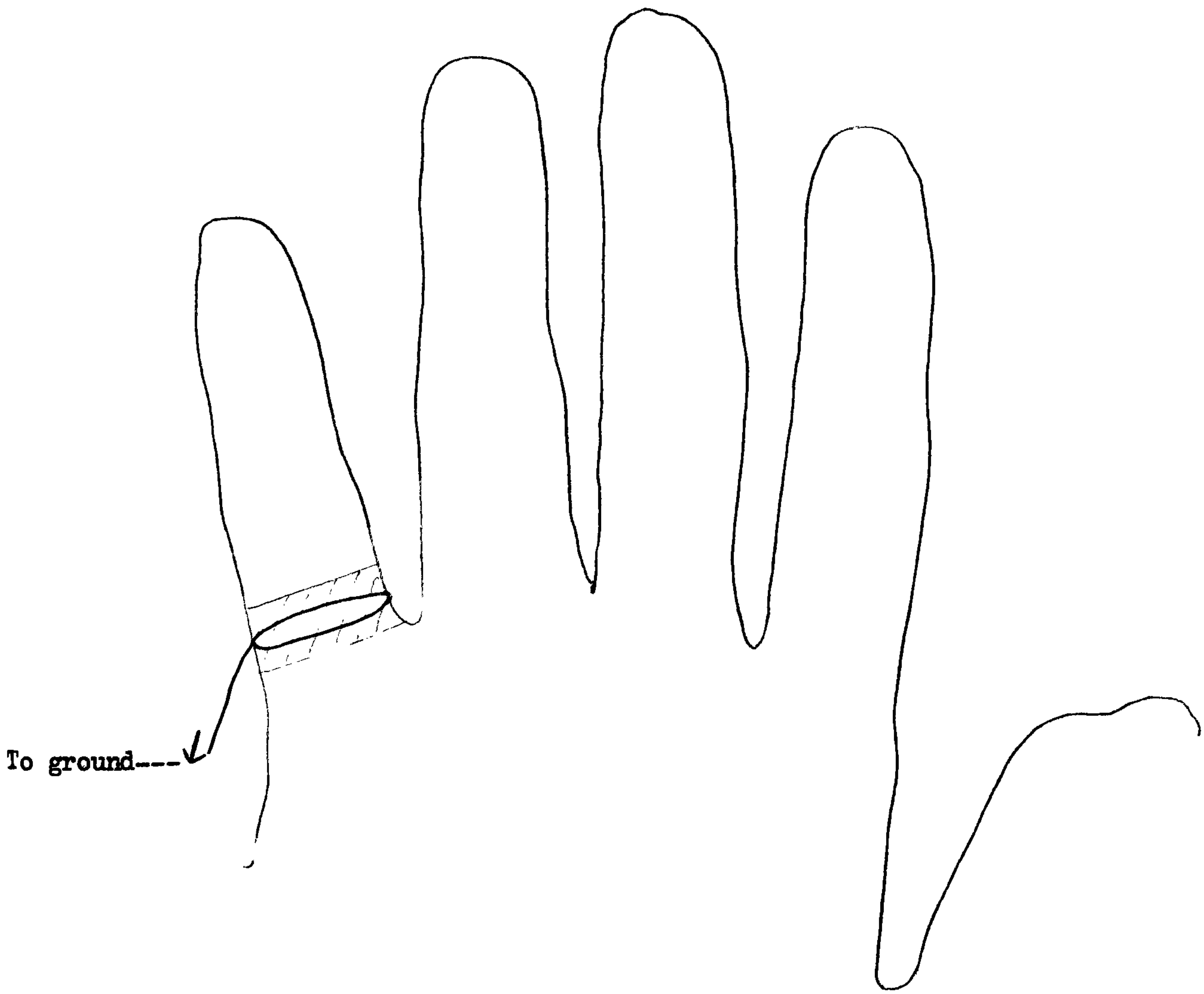


FIGURE IV

It encircled the base of his finger, and was itself encircled by ordinary black insulating tape to insure a good and repeatable contact. The subjects were permitted to develop their own "reading" techniques insofar as which area of the finger to use, how hard to press down on the pins, and how often to wipe moisture off the finger.

Subject A reported a particularly sensitive area on his little finger as shown below.

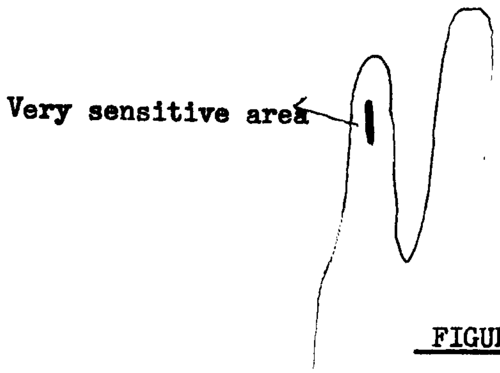


FIGURE V

Accordingly, he would tend to use this area in order to read relatively low voltages or very small differences in voltage and would tend to use the tip of his finger in order to read patterns presented at higher voltages. In other words, the most sensitive area is used for intensity detection, and the area that is most convenient in a tactual sense is used for pattern detection.

Subject B used her ring finger as it appeared to be the most sensitive. For some reason, some discomfort was felt when the ground wire was attached at the base of her finger. The ground was accordingly moved to about one inch from the top of her finger for all the tests.

It is of course important, for any practical benefit to ensue, for the subjects to be able to develop a natural reading technique which they find comfortable and which also produces consistent results. Although ground wires can never be re-attached in exactly the same way, and although pressure on the pins and the precise area of the finger used for reading could vary, both subjects developed, in a very short time, surprisingly consistent reading techniques.

PART B 1.) THE THRESHOLD EXPERIMENT

In this experiment the subject was presented with a row of ten pins and was told that only one pin was "on". He was asked to feel each pin with his fingertip and determine which one was "on". The base of his finger was electrically grounded and the "on" pin was selected randomly. The starting voltage was determined by previous experience and a trial run with the subject to acquaint him with what he was supposed to feel. He simply placed his finger on a pin and the voltage was turned up from zero until he felt something. The starting voltage for the experiment proper was then taken as five volts lower than this rough value.

If the subject was unable to correctly identify the "on" pin, then the voltage was raised one volt at a time until he was successful. At this point the experiment was repeated at the same voltage with a different pin "on", again randomly chosen. The probability of a chance success was thus one in a hundred.

Results of Threshold Experiments

Experiments were performed on Subject A for a period of several days, spread over about two and a half weeks.

On the first day, threshold was found to be 21 volts. Experimental procedure was as described on pp 8-9. (In previous experiments on the forefinger, abandoned for reasons discussed previously, Subject A had failed to detect 68 volts.) This 21 volt threshold was very "sharp", in that 20 volts was not identified at all. In the morning of the next day threshold was checked again (Subject A) and was found to be 21 volts again. Once more 20 volts was not identified. Later on that day the first problem arose. Threshold was re-checked and found to be up to 25 volts. The next day it was again 25 volts. The first idea then came to mind was that slight variations in the pulse width and frequency, caused by slight changes in the operating characteristics of the electronic components of the multivibrator, were producing these changes. A constant record had been kept of the pulse width and frequency, and the width had varied from 1.4 milliseconds to 1.2 milliseconds over the three days. ~~Frequency had been quite constant at 3 days.~~ Frequency had been quite constant at 30 cycles per second. Accordingly an experiment was performed in which the voltage was kept constant at various levels, during which (a particular level) the pulse width was varied grossly from 0.7 milliseconds to 2.0 milliseconds, and the frequency from 25 cycles per second to 35 cycles per second. Although these experiments were crude, Subject A reported no noticeable subjective difference at any one voltage level. He then tried licking his fingertips and the solution was found. Moisture on the fingertip greatly affects the resulting sensation. However, this variation in sensation never occurred within a short period of time. It was always a morning-afternoon or day to day variation. This suggests that environmental factors leading to different conditions of the skin are the dominant causes of these variations.

A week later with Subject A threshold was 40 volts. Four days later it was 39 volts at 9:00 A.M., and again 39 volts at 11:45 A.M. On both occasions 38 volts was not identified at all, not even when the subject was told which pin was "on". The pattern had thus evolved. Threshold could be remarkably consistent during a day or even for longer periods. However, long range changes are to be expected and they would appear to be caused by factors over which the subject has little control, such as environmental conditions. Otherwise, consistent threshold readings over even a short period of time would be hard to explain.

Subject B was only tested on one day. Her threshold was found to be 57 volts. She felt nothing at all at 56 volts. Two hours later it was again rechecked and again found to be 57 volts.

SUMMARY OF RESULTS

SUBJECT	DATE	VALUE (VOLTS)
A	Jan. 7th	21
A	Jan. 8th at 10 A.M.	21
A	Jan. 8th at 1 P.M.	25
A	Jan. 9th	25
A	Jan. 17th	40
A	Jan. 23rd at 9 A.M.	39
A	Jan. 23rd at 11:45 A.M.	39
B	Jan. 29th at 1 P.M.	57
B	Jan. 29th at 3 P.M.	57

For all experiments:

With reference to the accuracy with which voltage can be read on the oscilloscope:

Readings $<$ 60v. correct to $\pm \frac{1}{4}$ volt

Readings $>$ 60v. correct to $\pm \frac{1}{2}$ volt

i.e., to $\frac{1}{4}$ of the smallest scale division in each case.

2.) THE JUST NOTICEABLE DIFFERENCE (JND) EXPERIMENT

This was performed after the threshold value had already been determined.

The subjects were tested with two pins, one with threshold or higher voltage, and the other with a voltage two volts higher than the first. The subjects were allowed four runs, each of the four runs employing the same two voltages but with the pin carrying the lower voltage and the pin carrying the higher voltage randomly selected on each run. (The two pins were always adjacent to one another).

The subjects were required to state correctly (by feeling the pins) which pin was higher in intensity. The probability of a chance success over all four runs was thus one in sixteen. If the subjects were unsuccessful on any one of the four runs the difference was increased by one volt and the whole procedure was repeated until a voltage difference was reached at which the subjects scored four successes. The whole process was performed at overall voltage levels ranging from threshold to the stage where some discomfort was felt.

J.N.D. Results

The initial voltage level was determined by the results of the threshold experiments. A "success" constituted four correct identifications at a particular set of voltages.

Results are given in the order in which the experiments were performed. There seems to be a learning process involved; note successes at voltages at which there was an initial failure.

SEE NEXT PAGE FOR TABLE OF RESULTS

JND EXPERIMENTS

SUBJECT A - Jan. 17th, 1969 - Threshold for that date 40 volts

VOLTAGES	SUCCESS
40 - 42	NO
40 - 43	NO
40 - 44	NO
40 - 45	YES
42 - 47	YES
44 - 49	YES
42 - 46	YES
40 - 44	YES
40 - 43	YES
40 - 42	NO
42 - 45	NO
46 - 50	NO
46 - 51	YES
50 - 54	YES
54 - 58	YES
58 - 62	YES
62 - 66	YES
72 - 76	NO

JND EXPERIMENTS

SUBJECT A - Jan. 23rd, 1969

VOLTAGES	SUCCESS
40 - 42	YES
40 - 41	NO
45 - 47	NO
45 - 48	YES
50 - 52	NO
50 - 53	YES
55 - 58	YES
55 - 57	YES
60 - 62	YES
65 - 67	YES
70 - 72	YES
75 - 77	YES
80 - 82	YES

Threshold for Jan. 23rd

39 Volts at 9:00 A.M.

39 Volts at 11:45 A.M.

(i.e., before and after above expts.)

JND EXPERIMENTS

SUBJECT B - Jan. 29th, 1969

VOLTAGES	SUCCESS
57 - 59	NO
57 - 60	NO
57 - 61	NO
57 - 62	NO
57 - 63	YES
64 - 68	YES
64 - 67	NO
68 - 72	YES
68 - 71	YES
68 - 70	YES
72 - 74	YES
57 - 59	YES
64 - 66	YES

Threshold values for Jan. 29th

57 Volts at 1:00 P.M.
(i.e.,before and after above expts.)
57 Volts at 3:00 P.M.

Summary of J.N.D. Results

The following deals only with the best (i.e., the smallest J.N.D.s) obtained by each subject.

SUBJECT	VOLTAGE AT LOWER PIN	JND IDENTIFIED (VOLTS)
A	40 (Threshold)	2
A	45	3
A	50	3
A	55	2
A	60	2
A	65	2
A	70	2
A	75	2
A	80	2
	↓ Uncomfortably High	
B	57 (Threshold)	2
B	64	2
B	68	2
B	72	2
	↓ Uncomfortably High	

Mean JND = 2.2 volts

Standard Deviation = 0.12 volts

It is clear from the previous results that J.N.D.s remain approximately the same size as the level of stimulus intensity goes up. At first this might appear to be contrary to various well known laws of psychophysics e.g., $\Delta\psi \propto \psi$, where ψ represents subjective sensory intensity. However, as was pointed out earlier, voltage is not the measure of stimulus intensity. This is actually electric current. Thus, at higher voltage levels, the subject can, by touching the pins less firmly, be receiving the same current as at lower voltage levels. So, on the basis of these results, one cannot say anything regarding the laws of psychophysics, etc. Nevertheless, the overall level of intensity was definitely rising -- both subjects found the highest voltages used uncomfortable to work with. So the above explanation does not entirely account for the constant J.N.D. values.

3.) MORE THAN TWO PINS

The subject was presented with three or more pins, one carrying threshold voltage and the others threshold plus five volts, threshold plus ten volts, etc. The five volt value was based on the results of the JND experiment. The order of the pins was again randomly selected for all runs. The subject was required to subjectively rank the pins.

<u>Results</u>:

Subject A was tested with five pins with 40, 45, 50, 55, and 60 volts randomly dispersed over the pins. Each pin had a different voltage. He was asked to rank them subjectively from lowest to highest.

This proved to be quite simple although the procedure took from five to ten minutes. Subject first located "lowest" pin, then compared the next two "higher" pins with one another, and then finally compared the last two. The experiment was performed twice with differing voltage arrangements (although still employing the five voltages as listed above). Subject was completely successful on both occasions.

Subject B had had far less experience on the machine than had A. She was accordingly tested with only three pins with 60, 64, and 68 volts randomly dispersed. Successful identification required only 20 seconds.

4.) PATTERN RECOGNITION

The subject was presented, on a 5x5 array of pins, with some of the Donaldson-Gough Alphanumeric Characters (cf. Ref. 6)

These characters are illustrated below:

E S 2 3 8 9

They were presented on the array of pins as shown below:

• — represents an "on" pin
. — represents an "off" pin

E 9 etc.

The voltage at the "on" pins was threshold plus five volts. The subject was first familiarized with the characters, and then presented with randomly chosen examples which he was required to identify.

Results:

Subject A was tested with the characters E (e), 5 (s), 2 (2) and 9 (9) presented on a 5x5 array of pins at 26 volts. Threshold that day was 21 volts. After he was familiarized with all four letters, random selections from the four were presented individually. He was successful on all three occasions tested, taking about 30 seconds each time.

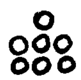
Further experiments were not performed because it became apparent that when one is limited to an array of pins such as in this device, it becomes easy for a subject to identify anything simply by memorizing which pins in which row or column were "on" and then piecing together all the information at the end. This situation is thus somewhat artificial.

5.) DIFFERENT PIN SPACING

Pins were moved closer together in order to determine the effect of this on the subjects' ability to work on two mor more pins simultaneously with the same finger. For this purpose, additional pins were placed in stiff cardboard so as to simplify insertion and removal, and these pins were connected to pins on the board.

Results:

Subject A was tested with seven pins arranged as shown below.



Spacing between pins was $\leqslant 0.5$ mm. as compared with 13 mm on the board.

It was discovered that if the subject touched two pins simultaneously with one finger, and if one or both pins were "on", then he could not say which pin was "on" or whether both were "on". It appeared that the sensation was felt at the same place on his finger regardless of which area or areas of the finger were touching an "on" pin. In order to spatially isolate a pin from the others surrounding it, it was necessary for the subject to employ the extreme tip of his finger. As pointed out on page 9 , this was not the most sensitive area. Accordingly, he could only subjectively isolate an interior "on" pin if the voltage waa sufficiently high (twice threshold in this case).

CONCLUSIONS

1.) The subjects expressed no feelings of physical discomfort arising from the stimuli to which they were subjected.

2.) The threshold values obtained were always "sharp", in that values just one volt less than threshold could not be detected. The value of threshold was different for each subject, but for individual subjects it was not detectably different when measured at the beginning and end of periods ranging from two hours to a day. It did change over longer periods.

3.) The mean Just Noticeable Difference for thirteen readings from two subjects was 2.2 volts, with a standard deviation of ~~0.13~~ 0.12 volts. These results were obtained at stimulus levels ranging from threshold to the beginning of discomfort and over the whole range there were only small, unsystematic variations in the JND values.

4.) Subject A was completely successful in all his attempts to identify some examples of the Donaldson-Gough Alphanumeric characters. However, owing to the regular configuration of the pins on the board, his capabilities in this regard were not exhausted.

5.) Subject A was successfully able to rank five pins at which 40, 45, 50, 55, and 60 volts were randomly arranged. Subject B was successful in a similar experiment involving three pins and 60, 64, and 68 volts.

6.) Experiments were performed on subject A in which pins were spaced as close as 0.5 mm. apart. He was required to detect which were "on" and which were "off". It turned out that he was successful only for pins that could be touched individually. When two or more pins were touched simultaneously with the same finger, the condition of each pin could not be stated.

DISCUSSION

Two points about the threshold experiments are worth discussing.

1. In all cases, threshold was very "sharp". A voltage just one volt below threshold could not be felt even when the subjects were told that the pin being felt was "on".

2. In many instances, the threshold value was precisely the same over periods of hours or even sometimes days. This is surprising in view of the many factors which it would seem could change body resistance, e.g., environmental changes, perspiration, difference in pressure in finger on pin, different areas of finger used, different positions for the ground wire, etc.

The above two factors would seem to suggest that the value of threshold depends primarily on the subjects' physiological make-up, and that different subjects would have their own unique thresholds. Of course, variations in the values of threshold voltage need not adversely affect the design of a "Reading Machine". The user would merely dial the voltage to suit himself for any particular occasion. This is analogous to a sighted person's adjustment of illumination for reading purposes. Threshold could just be any voltage; the material to be "read" would be represented as voltages above threshold, where threshold represents black or step 1 of a gray scale, etc.

As noted on page 20, J.N.D. values are quite small compared with the range of voltages used. Subject B could probably have been subjected to quite higher voltages (higher than 72 volts) had she become more familiar with, and possibly less apprehensive of the procedure. Subject A had a working range of more than 40 volts and a J.N.D. of about two volts which would imply that about 20 "steps" are theoretically possible. A "print reading" machine would, of course, require only two steps, corresponding to black and white.

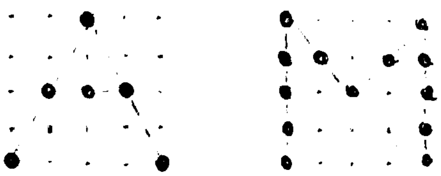
PRACTICAL PROTOTYPE OF READING MACHINE

For simplicity, consider the printed type to be:

A.) white print on black paper

B.) block capitals as on an ordinary typewriter.

Of course, whilst printed material does not normally appear in these forms, further refinements could probably take care of these problems. Even with the two restrictions listed above, printed material in this form would still overcome the latter two objections to Braille listed on page one. With this set-up, "reading" by the blind person would be similar to the process involved in reading the Donaldson-Gough characters (cf. page 9). The "eye" of the machine would consist of a 5x5 bank of photocells each designed to "see" a very small area so that the letters in the printed material are "seen" as follows:



where ● represents an illuminated photocell

etc.

actual size of capitals
in ordinary type about
3x3 millimeters

A 5x5 array of photocells would be sufficient to uniquely identify all 26 letters (in capitals) of the alphabet. In case the design of photocells to "see" very small areas, and still to submit to the current and voltage requirements of the apparatus proves very difficult, it would seem possible to optically magnify the letters before they are "seen" by the photocells.

Of course, those persons well acquainted with the current state of the art of electronics would no doubt be able to suggest further ideas and refinements. It would appear at least, that the ability to communicate by means of tactile electrical sensations offers many interesting possibilities in many fields. Marshall McLuhan,[1] for example, speaks of a possible trend from "VISUAL TO TACTILE" amongst the young people of today.

[1]Playboy Magazine, March 1969.

Acknowledgment

I would like to acknowledge the advice and assistance of the following persons:

Professors Hollis N. Todd, Burt H. Carroll, and John F. Carson, Photo Science Department Rochester Institute of Technology.

Professor Norman Coombs of the Department of General Studies.

Professor George Thompson of the Department of Electrical Engineering.

Mrs. Evelyn Hartigan, Rochester Institute for the Blind

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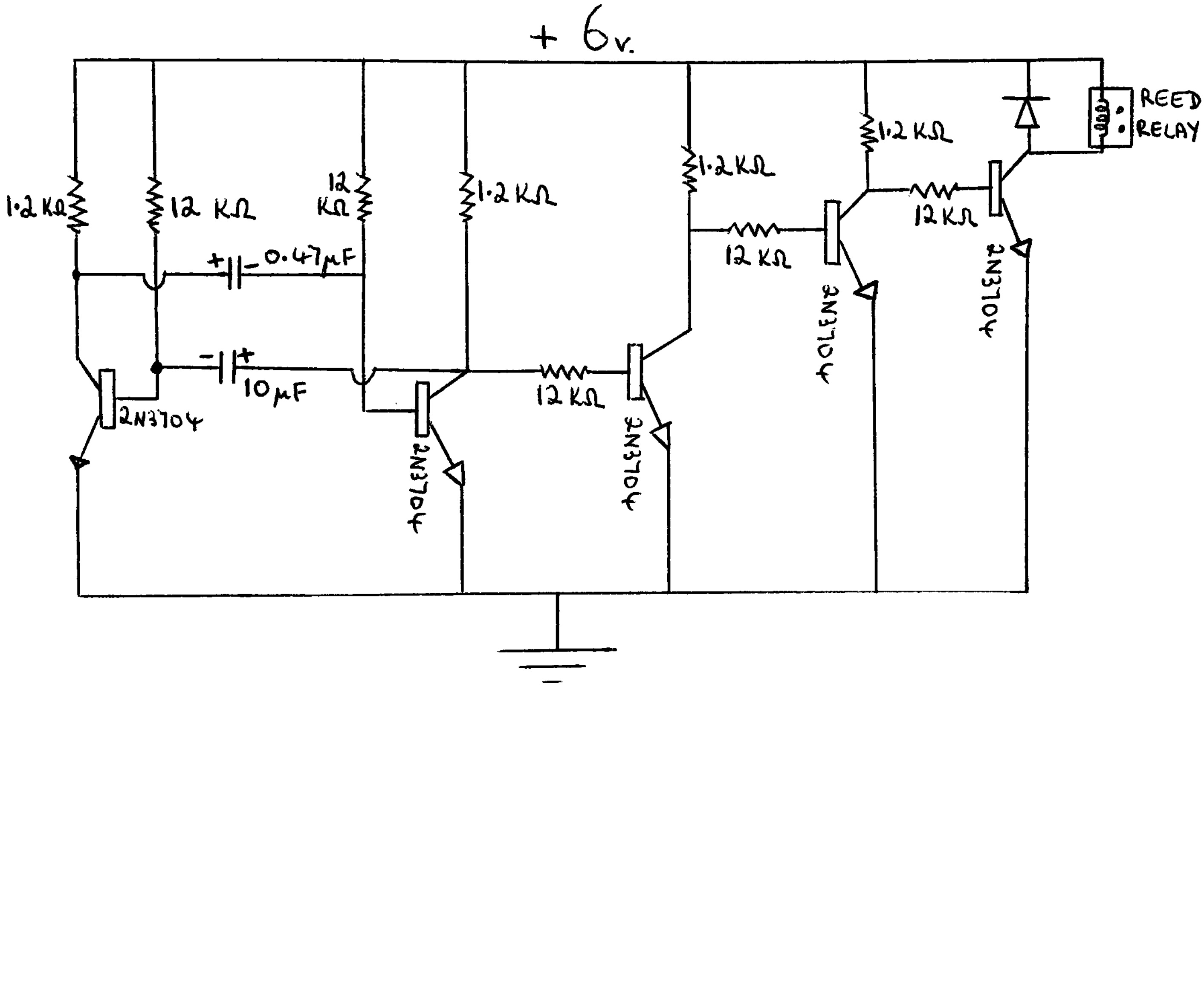
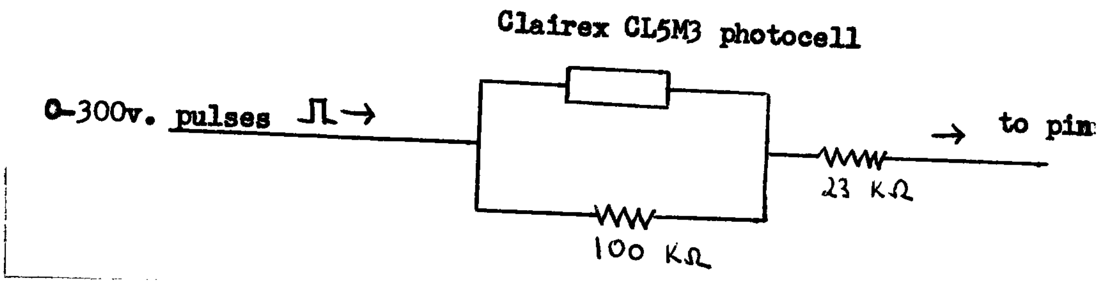
APPENDIX I

MULTIVIBRATOR CIRCUIT DIAGRAM



APPENDIX II

The procedure shown below was used to obtain a simple practical set-up of the device schematically illustrated on page 1.



The resistance of the photocell in the above circuit drops as the amount of light falling on it is reduced. Thus, the voltage at the pin will rise or fall according to the amount of light on the photocell. Therefore, a 10x10 array of photocells, each in a circuit of the type shown above, and each connected directly to a pin, will produce a "voltage picture" of the luminance distribution at which the photocells are pointed. This is shown diagrammatically on the next page.

APPENDIX II (continued)